Spatial distribution of population and health benefit evaluation for effectiveness of $PM_{2.5}$ control measures in Taiwan

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Abstract

Our study used Taiwan Air Benefit and Cost and Attainment Assessment System (ABaCAS-Taiwan) which integrated the Taiwan Emission Control Cost Analysis System (TECAS), Response Surface Modelling (RSM), and Benefits Mapping and Analysis Program (BenMap) to evaluate the population of exposure and health benefits through various control strategies based on Clean Air Action Plan (2015-2020) proposed by Taiwan EPA. A total of 21 scenarios including 7 mobile, 6 stationary and 8 fugitive source control scenarios were simulated in our study. Comparison between stationary control measures, showed that more $PM_{2.5}$ emissions could be reduced and contribute to the improvement of annual average $PM_{2.5}$. We used spatial cumulative reduction of $PM_{2.5}$ concentration and population living in the attainment area to evaluate the effectiveness of various control measures. By installing soot filters on 38,000 diesel vehicles, eliminating one million two-stroke motorcycles and promoting purchase of 600,000 e-bikes, reduction of open burning, dust emission on the road and construction are amongst top five measures improving the $PM_{2.5}$ levels in the areas with more than 15,000,000 population. The costs of these top 5 control measures are estimated based on governmental investment and health benefits with avoiding hospital admission of cardiovascular and respiratory diseases, and human lives saved.
Keywords: ABaCAS-Taiwan, BenMap, PM2.5, population, cost-benefit

1 Introduction

The implementation of air pollution control strategies in Taiwan have successfully reduced 45.7% of emission of PM_{10}, SOx, NOx, NMHC, CO, and Pb in 2016 alongside the increasing environmental burdens, urbanization, growth of economics and human activities. Fine particulate matters ($PM_{2.5}$), an important air pollutant receiving intense regulatory attention recently is still far from the attainment goal (15 $\mu g/m^3$ for annual average) for most of the geographical area in Taiwan. Statistical reductions of ambient levels of $PM_{2.5}$ have been observed for many control measures that has been implemented in these years. However, only around 3.61% population in the island living in the area (mostly east coastline) attained the annual average concentration lower than 15$\mu g/m^3$ (Environmental Protection Administration, R.O.C.(Taiwan), 2016).

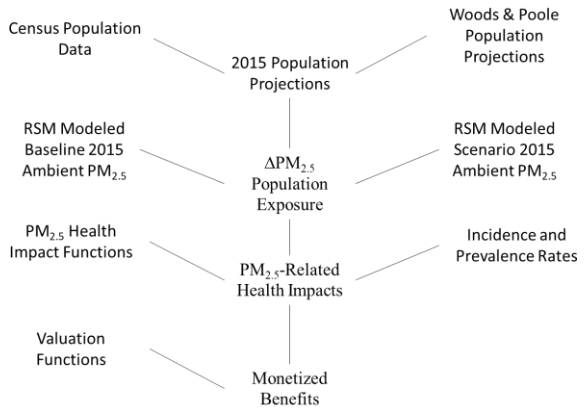
Human exposure to $PM_{2.5}$ have been proved to have diverse health adverse effects from many epidemiological studies. Reducing the human exposure levels and their impacts on health outcomes is therefore critical in response to various control measures. Our study used Taiwan Air Benefit and Cost and Attainment Assessment System (ABaCAS-Taiwan) which integrated the Taiwan Emission Control Cost Analysis System (TECAS), Response Surface Modeling (RSM), and Benefits Mapping and Analysis Program (BenMap) to evaluate the population of exposure and health benefits through various control strategies based on Clean Air Action Plan (2015-2020) proposed by Taiwan EPA (Environmental Protection Administration, R.O.C.(Taiwan), 2017).

2 Materials and Methods

ABaCAS-Taiwan was the version based on ABaCAS system jointly developed by an international team of scientists and U.S. EPA (http://www.abacas-dss.com/abacas/Default.aspx). Our study used emission inventory conducted by Taiwan EPA (TEDS 9.0, 2013) to compare spatial distribution of $PM_{2.5}$ concentrations, population living areas of under 15ug/m^3, and avoidance of deaths and monetized health benefits to understand the cost-benefit for different control measures proposed by Taiwan EPA. A total of 21 scenarios including 7 mobile, 6 stationary and 8 fugitive source control scenarios were simulated in our study. Per various scenarios, TECAS can display the emission reduction information including the location, type of emission source, and the cost of control measures. RSM system allows us to estimate the air quality improvement namely the reduction of $PM_{2.5}$ concentrations in 3km*3km grid across the island based on different scenarios. The BenMAP is a geographic information system-based program that estimated the health benefits associated with changes of air pollution (US EPA, 2015; Chen et al., 2017).

The database of population distribution, mortality and hospital admission associated with $PM_{2.5}$, health impact functions, statistical value of life, and medical costs were established to estimate the population living in attainment area and health benefits in dollars.

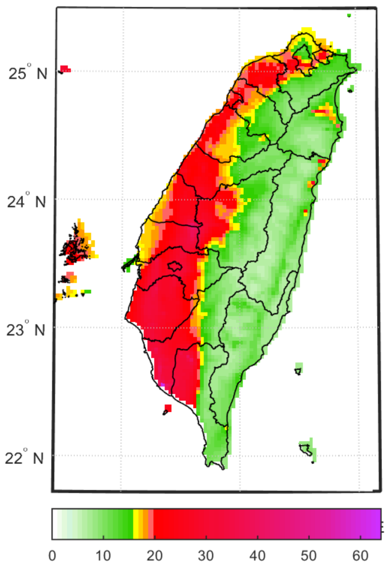
Figure 1. The data input of BenMAP



3 Results

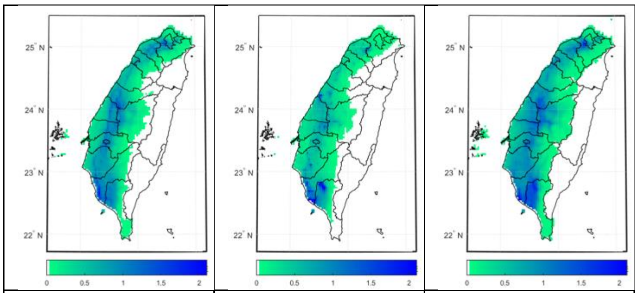
When 21 control measures were implemented, only east coastline will achieve the attainment goal ($PM_{2.5}$ annual average < 15 μg/m^3) in 2020 with only 4.12% population living in attainment area (Figure 2).

Figure 2: PM2.5 concentration simulated by RSM when implementation of 21 control measures



Comparison between stationary control measures, fugitive and mobile source control could reduce more $PM_{2.5}$ emissions and contribute to greater area of Taiwan with improvement of annual average $PM_{2.5}$ concentrations in simulation (Figure 3). We use spatial cumulative reductions of $PM_{2.5}$ concentration and population living in $\Delta PM_{2.5}$ >0.1 μg/m^3 to evaluate the effectiveness of various control measures. Installing soot filters on 38,000 diesel vehicles, eliminating one million two-stroke motorcycles and promoting purchase of 600,000 e-bikes, reducing open burning, dust emission on the road and construction are amongst the top 5 most effective measures improving the $PM_{2.5}$ levels in the areas with more than 15,000,000 population.

Figure 3: The reduction of PM2.5 simulated by RSM by various scenarios controlling mobile, stationary and fugitive sources.



a. Mobile | b. Stationary | c. Fugitive

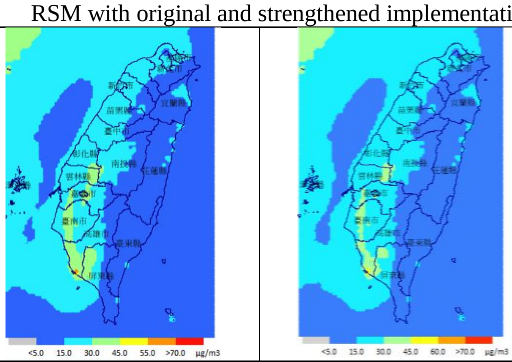
The costs of these top 5 control measures were further estimated based on governmental investment and health benefits with avoiding hospital admission of cardiovascular and respiratory diseases, and avoided deaths in dollars were estimated by in these five scenarios. Reducing open burning and emission from construction were the most cost-effective control measures with the ratio of benefit and cost in 79 and 43 (Table 1).

Table 1: Health Benefits by top 5 control measures

Control measures	Control Cost (million USD)	△PM2.5 (μg/m^3)	Long-term effects: Avoid Deaths and Monetized Benefits — All cause deaths (Monetized value: Million USD)	Short-term effects: Avoid HAs and Monetized Benefits — Cardiovascular disease HAs (Monetized value: Million USD)	Respiratory disease HAs (Monetized value: Million USD)	$\frac{Benefits}{Cost}$
Installing soot filters on 38,000 diesel vehicles	318.90	0.4104 (0.002~1.1703)	563(2,452)	409(1,779)	189(821)	16
Eliminating one million two-stroke motorcycles and promoting purchase of 600,000 e-bikes	97.54	0.1571 (0.0007~0.4402)	216(940)	157(684)	73(316)	20
Reducing open burning	17.30	0.1128 (0.0007~0.3441)	152(662)	111(482)	51(221)	79
Reducing dusts on the road	97.01	0.3126 (0.0013~0.9605)	420(1,829)	305(1,328)	140(610)	9
Reducing emissions from construction	45.61	0.1641 (0.001~0.534)	221(962)	161(700)	74(322)	43

We would like to strengthen policy implementation by doubling the top 5 control measures on reducing emissions. Compared to the original action plan, doubling the top 5 control measures can effectively reduce the annual average $PM_{2.5}$ concentrations on south-eastern regions of Taiwan (Chiayi County, Chiayi City, Tainan City, Kaohsiung City, and Pingtung County) where with higher population density (Figure 4). Strengthened policy implementation can further reduce annual average $PM_{2.5}$ levels close to 3 $\mu g/m^3$ which contribute to 1,273,918 peoples living in attainment areas (< 15 $\mu g/m^3$) comparing to 956,811 peoples by original action plan (Table 2) meaning effectively improve the ambient levels in populated areas. We will avoid 3,961 deaths through decreasing $PM_{2.5}$ with economic benefit of 17,237 million USD by strengthened policy implementation comparing to avoid 2430 deaths with economic benefits of 10,573 million USD. Strengthening the top 5 effective control measures in the action plan will increase the government investment around 576 million USD. However, an increase in 6,663 million USD economic benefits from avoiding deaths were estimated. With high benefit-cost ratio close to 12, we highly recommend strengthening these five control measures for effectively reducing population exposure and achieving attainment goal in the future. Cost-benefit evaluations based on emission reduction, ambient air pollution simulation, and health benefit estimations should also take into account in the policy making in the future.

Figure 4: Annual average PM2.5 concentration simulated by RSM with original and strengthened implementation



a. original policy | b. strengthened implementation

Table 2: Estimated avoided deaths and hospital admissions and monetized benefits associated with improving PM2.5 levels

	$^a\triangle PM_{2.5}$ ($\mu g/m^3$)	Population living in $PM_{2.5} < 15$ $\mu g/m^3$	Long-term effects Avoid Deaths and Monetized Benefits All cause deaths (Monetized value: Million USD)	Short-term effects Avoid HAs and Monetized Benefits Cardiovascular disease HAs (Monetized value: Million USD)	Respiratory disease HAs (Monetized value: Million USD)
Original Policy	1.7998 (0.0054~5.1603)	956,811	2430 (10573.17)	461(1.48)	734(2.02)
Strengthened Implementation	2.9533 (0.0094~8.2365)	1,273,918	3961 (17236.58)	757(2.43)	1201(3.3)

[a] Using annual average concentration in 2015 as the baseline: 23.6569($\mu g/m^3$)

4 Conclusions

We integrate the population data into the evaluation procedures of air quality control policies and demonstrate installing soot filters on 38,000 diesel vehicles, eliminating one million two-stroke motorcycles and promoting purchase of 600,000 e-bikes, reducing open burning, dust emission on the road and construction are amongst the top 5 most effective measures improving the $PM_{2.5}$ levels in population living area. Strengthened policy implementation, doubling the top 5 control measures can further reduce annual average $PM_{2.5}$ levels close to 3 $\mu g/m^3$ which contribute to 1,273,918 peoples living in attainment areas (< 15 $\mu g/m^3$) comparing to 956,811 peoples by original action plan meaning effectively improve the ambient levels in populated areas. With high benefit-cost ratio close to 12, we recommend strengthening these five control measures for effectively reducing population exposure and achieving attainment goal in the future. It also shows that current policy proposed in Clean Air action plan could be re-evaluate the effectiveness in proper period.

5 References

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